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This issue contains articles on the following subjects: 1.Development and Construction of an Aviation Strength-Screening Device; 2.Words From the Chief Scientist; 3.The Power and Limits of Problem Solving: Status and Future Prospects of AI Applications; 4.A Conversation With Herbert Simon; 5.Navel Air Warfare Center Aircraft Division Crewstation Technology Laboratory

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VOLUME IX: NUMBER 2 (1998)

CSERIAC GATEWAY

PUBLISHED BY THE CREW SYSTEM ERGONOMICS INFORMATION ANALYSIS CENTER

In this issue:

CSERIAC is a United States Department of Defense Information Analysis Center administered by the Defense Technical Information Center, Ft. Belvoir, VA, technically managed by the Air Force Research Laboratory Human Effectiveness Directorate, Wright-Patterson Air Force Base, OH, and operated by Booz·Allen & Hamilton, McLean, VA.

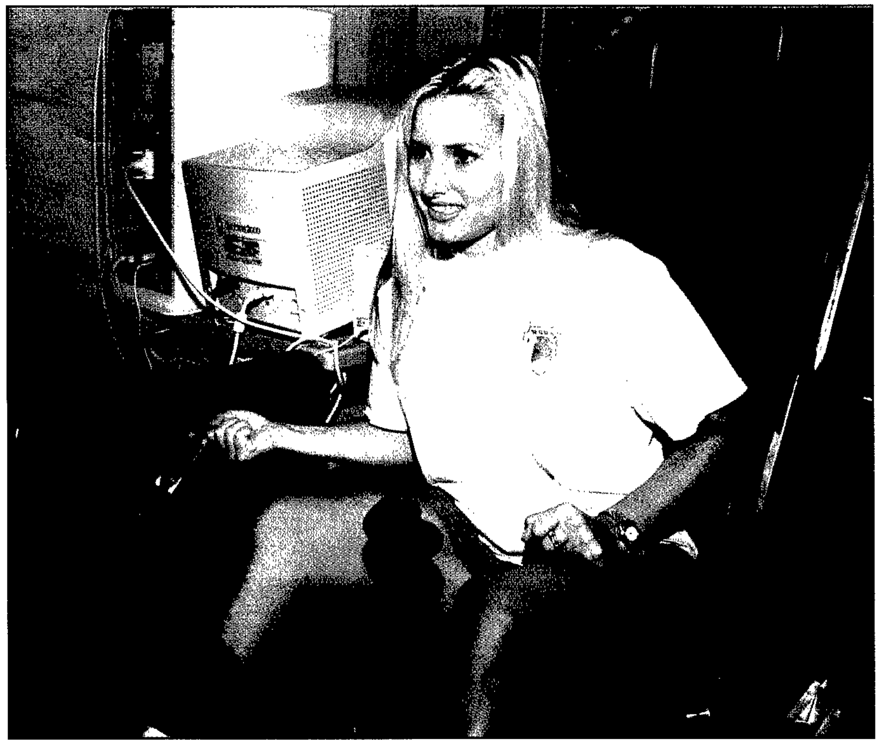

Figure 1. Subject being tested using the T-34C manual landing gear crank.

Development and Construction of an Aviation Strength-Screening Device

J. L. Saxton, J. W. McDaniel, J. Quinn, & T. L. Pokorski

A state-of-the-art, computer-based cockpit simulator for testing pilots' strength was developed as a joint effort between the Naval Aerospace Medical Research Laboratory (NAMRL), Pensacola, Florida, and the former Armstrong Laboratory Human Engineering Division (now the Air Force Research Laboratory Crew System Interface Division), Wright-Patterson Air Force Base, Ohio. This unique device has all major cockpit controls, including center stick aileron/elevator, wheel aileron/elevator, rudder pedals, center-pull ejection handles, face-curtain ejection handle, helicopter collective control, and emergency landing gear crank. It houses a computerized data acquisition system to administer sophisticated test protocols. Current Navy plans include using this customized strength-screening device to evaluate strength-conditioning programs, to assist in matching pilot candidates to specific aircraft, and to better specify performance requirements with future aircraft design.

Current Department of Defense (DoD) policy authorizes both male

Continued on page 2

and female officers to become pilots in all aircraft. Presently, the Navy uses two types of general physical strength/endurance evaluations for naval aviators: the Navy Physical Readiness Test (PRT) and specific physical training activities in the Naval Aviation Schools Command (NASC) physical training curriculum. Although both programs are gender- and aged-normed, they have not been validated against specific aviation occupational standards. Significant physical strength is required for both routine and emergency tasks (e.g., high-G maneuvers, manual landing gear extension, ejection seat actuation) found in military aircraft. This strength-screening device was developed to determine strength and endurance capability by testing aircraft-specific tasks.

The first phase of the project surveyed each of the aviation communities to identify strength tasks related to their specific aircraft. Once the tasks were defined, the actual forces required to perform those tasks were verified from actual measurements or through reference documentation such as flight test data and military specifications. The screening device was subsequently designed to simulate specific tasks identified for each aircraft type. The aircraft/control combinations listed below were based on the survey information, relative abundance in the fleet, and how long the aircraft was projected to be used in the fleet. The following aircraft/controls were simulated in the device:

- F-18 Hornet stick (elevator and aileron)
- F-18 Hornet rudder pedals
- P-3 Orion wheel (elevator and aileron)
- UH-60 Seahawk collective
- NACES ejection seat lower ejection handle (seat back/pan, harness)
- GRU-7 ejection seat face curtain ejection handle (and headrest)
- T-34C manual landing gear crank

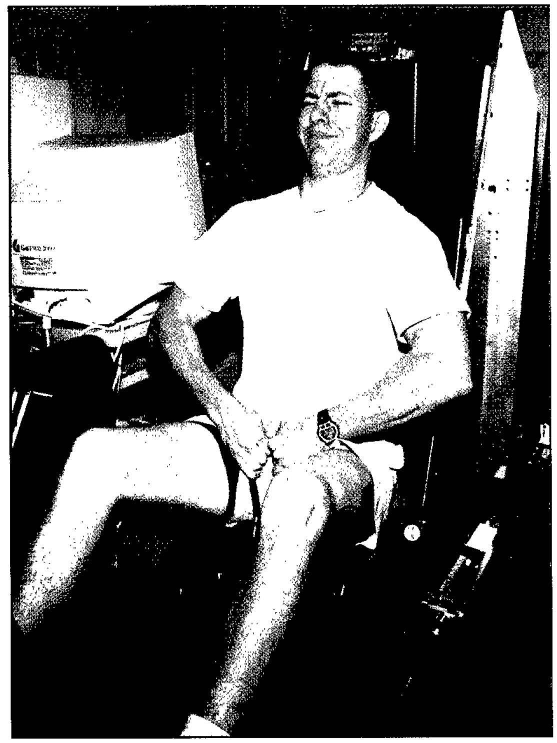

Figure 2. Subject being tested using the F-18 ejection seat handle.

The strength-screening device incorporates the features listed in Table 1.

To prevent subjects from adjusting the seat to an unrealistic position, an adjustable sighting device aids the subject in adjusting the seat (relative to the controls) to position the eye along the over-the-nose vision line for each aircraft (design eye height). Each seat-adjust "box" is stored in the computer memory so the seat and pedals cannot be adjusted outside the realistic range.

Table 1. Features of the Strength-Screening Device

- Menu-driven, computer-based simulator controller/data acquisition system.
- Second (repeater) computer display to provide instructions/feedback.
- High-fidelity controls have range of motion, resistance, size, and shape of selected aircraft.
- Can be converted from a stick to wheel control (or vice versa) by one person within 1 minute without any tools.
- Automated testing of maximum static strength.
- Automated testing of instantaneous (demonstration) testing, which provides real-time feedback of actual force(s).
- Precision electronic load cells to measure forces applied to controls.
- Adjustment of seat and pedals by computer allows cockpit geometry of any Navy aircraft to be represented: 8 inches vertical seat adjustment; 8 inches horizontal seat adjustment; and 12 inches pedal adjustment.

Figure 3. Subject being tested using a stick/left rudder pedal combination.

Using this approach, the performance interaction of body size with strength can be simultaneously evaluated. The combination of the adjustable sighting device and the extra-large range of adjustment allows the strength test cockpit to simulate any Navy aircraft.

Except for the isometric face-curtain ejection control, all controls are dynamic with the same resistance to movement as the aircraft they represent. Springs in the control linkage provide high-fidelity force profile within the limits of control movement. The controls are instrumented, precision-load cells that measure the total force applied to a control, even if it has already been pushed against its stop.

Some of the components of the strength-screening device, such as the ejection handles, NACES seat pan, and seat back (including cushions) are parts from actual aircraft, while the plastic stick grip and the hollow aluminum wheel were replaced with stronger cast steel.

Currently all naval aviation candidates must be able to operate the T-34C emergency landing gear crank. This crank is located on the right side of the cockpit (see Fig. 1), and operates similarly to a window crank in an automobile. A total of 42 turns is required to completely lower the landing gear. For the first 28 turns, the resistance is a mere 5 pounds. Beyond 28 turns, resistance increases dramatically to 25 pounds, as the wheels move further into a 110-knot wind. To simulate the effect of wind resistance, the gear crank on the simulator employs a computer-controlled electric brake that increases resistance nonlinearly as the number of revolutions increases.

The strength-screening device seat is a hybrid, combining a NACES seat bottom with a GRU-7 top, equipped with a face-curtain. The face-curtain ejection handle is the only isometric control in which the subject pulls as hard as possible on a stationary handle. This simulates the most demanding part of the task, pulling the handle out of its stowage latch. Because subjects are tested without helmets, the headrest is offset forward so the head will have the correct geometry with respect to both the seat back and the face-curtain handle. While only 40 pounds of force are required to pull the lower ejection handle, a precision electronic load cell can measure the maximum jerk force beyond 300 pounds (see Fig. 2). As with the other controls, total force is measured, even after the handle has reached the end of travel.

The operational sophistication resides in the modular software and the state-of-the-art computer data acquisition system. The menu-driven computer displays allow the test examiner to select from 181 different test combinations. Figure 2 shows the examiner's station behind and to the right of the subject. Further variations result from being able to select any number of combinations of forces and durations in the

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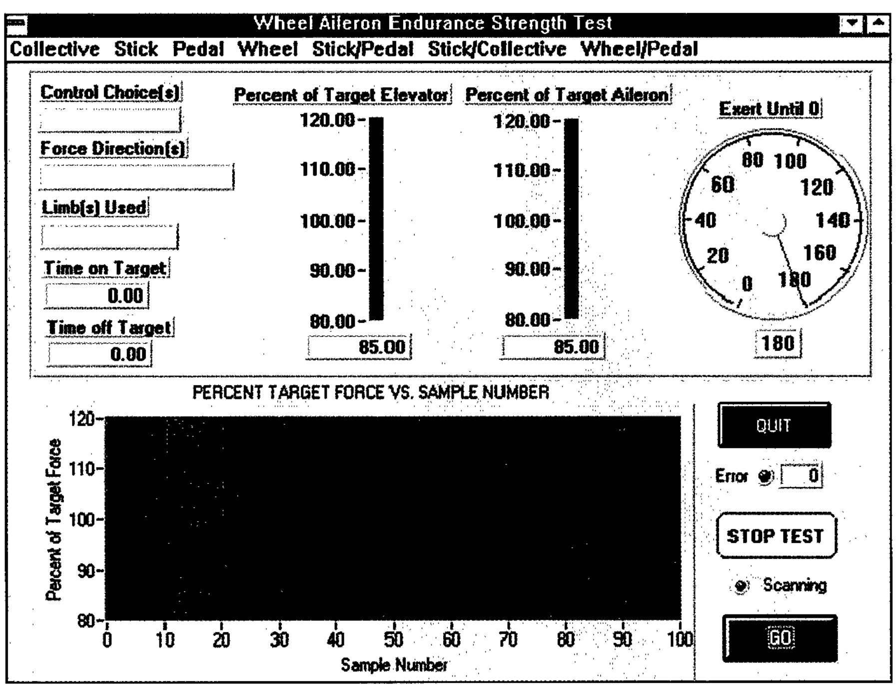

Figure 4. Computer screen for an endurance test.

endurance tests. Choices from the menu enable a variety of different test protocols including a maximum effort test, endurance test, and instantaneous test. Even common combinations of controls (e.g., stick/rudder pedal, wheel/rudder pedal, stick/collective) are possible when conducting endurance and instantaneous tests. The subject's display, shown in Figure 3, pictures a student performing a stick/left rudder pedal combination test.

Figure 4 shows an endurance test computer screen. After selecting a control or control combination from the top bar of the display, the computer prompts the operator to enter the direction of force, the target force(s) for the control(s) selected and the duration of the test (seconds). To complete an endurance test, subjects must maintain a minimum 95% of the target force(s) on the control(s) for the duration of the test. A clock-type countdown timer displays the time remaining to both the examiner and the student.

Test data are stored in the computer in two different formats. One type of file includes the names of all parameters together with their selected or measured values. The other type of file contains only numerical values for importing into a database or spreadsheet. Both files are automatically created when the operator chooses to save the data from any of the tests.

This joint program illustrates how the services cooperate to share expertise and technology to save time and money for the military. The development of the strength-screening device was a challenging hardware/software system acquisition that included developing requirements, engineering, designing, building, testing, documenting, and even training. Although the device is complete, under a 5-year Memorandum of Agreement, the Navy and Air Force labs will continue to share data and technology for their mutual benefit.

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Obituaries

World-renowned human factors engineer and scientist **Dr. Julien M. (Chris) Christensen** died at age 79 on July 10, 1998. During more than 50 years, "Chris" was a pioneer and world-class leader in human factors engineering, including his work as an engineer/scientist at the US Air Force Paul M. Fitts Human Engineering Division. He was the third Division Chief, from 1956 to 1974. Details at the CSERIAC website.

Dr. Walter F. Grether died June 10, 1998 at age 86. With Dr. Paul M. Fitts he founded the US Army Air Force Psychology Branch at Wright Field, near Dayton, in August 1945. This later became the Paul M. Fitts Human Engineering Division. In 1949 he succeeded Dr. Fitts as the second Division Chief until 1956, when he became Director of the Behavioral Sciences Division.

Howard Arnoff, Naval Air Systems Command Senior Aviation Psychologist, died on August 26 after 30 years of government service. Howard pioneered the application of human factors to aircraft design and acquisition. Despite a slowly worsening lung condition, he continued to work, even volunteering for extra projects.

Calendar

October 2-4, 1998
Baltimore, MD, USA

Inter-Society Color Council Annual Meeting. Contact ISCC, 11491 Sunset Hills Road, Reston, VA 20190.
Tel: +1-703-318-0263
Fax: +1-703-318-0514
Email: iscc@compuserve.com

October 5-9, 1998
Chicago, IL, USA

42nd Annual Meeting of the Human Factors and Ergonomics Society. Hosted by the Chicago Metropolitan Chapter. Contact HFES, PO Box 1369, Santa Monica, CA 90406-1369.
Tel: +1-310-394-1811
Fax: +1-310-394-2410

COME SEE OUR BOOTH !

October 14-15, 1998
Wright-Patterson AFB, OH, USA

Alternative Control Technologies — Human Factors Issues. Contact Dr. Grant McMillan, AFRL/HECA, Building 33, 2255 H Street, Wright-Patterson Air Force Base, OH 45433-7022.
Tel: +1-937-255-8766
Fax: +1-937-255-8752
Email: gmcmillan@al.wpafb.af.mil

October 20-22, 1998
Yellow Springs, OH, USA

A hands-on short course in anthropometric measurement. Lecture topics include automated techniques, human variability, and data and product applications. Also, 3-D scanner demonstration. Contact Anthropology Research Project, PO Box 307, Yellow Springs, OH 45387.

November 2-5, 1998
Arlington, VA, USA

Defense Technical Information Center (DTIC) Annual Users Meeting, "Maintaining the Information Edge." Contact Ms. Julia Foscue, DTIC, 8725 John J. Kingman Road, Suite 0944, Ft. Belvoir, VA 22060-6218.
Tel: +1-703-767-8236
Fax: +1-703-767-8228
Email: jfoscue@dtic.mil
WWW: http://www.dtic.mil

November 17-20, 1998
Scottsdale, AZ, USA

6th Color Imaging Conference: Color Science, Systems, and Applications. Contact Society for Imaging Science & Technology, 7003 Kilworth Lane, Springfield, VA 22151.
Fax: +1-703-642-9094
Email: info@imaging.orgResearch Project, PO Box 307, Yellow Springs, OH 45387.
Tel: +1-937-767-7226
Fax: +1-937-767-9350
Email: belva.hodge@arp-online.com
WWW: http://www.arp-online.com

November 18-20, 1998
Gifu, Japan

VSMM 98, "Futurefusion."
Contact International Society on Virtual Systems and MultiMedia, Virtual Systems Laboratory, Gifu University, 1-1 Yanagido, Gifu 501-1193 Japan.
Tel/Fax: +81-58-293-3157
Email: vsmm-sec@vsmm.vsl.gifu-u.ac.jp
WWW: http://www.vsmm/vsl.gifu-u.ac.jp/vsmm98

November 22-26, 1998
Sydney, Australia

7th International Conference on Noise as a Public Health Problem, Noise Effects '98. Contact Secretariat, GPO Box 128, Sydney NSW 2001, Australia.
Tel: +61-2-9262-2277
Fax: +61-2-9262-3135
Email: noise98@tourhosts.com.au,
WWW: http://www.acay.com.au/~dstuckey/noise-effects98

June 15-17, 1999
Linkoping, Sweden

Annual International Conference on TQM and Human Factors. Contact Jorgen Eklund, Division of Industrial Ergonomics, Linkoping University, S-58183 Linkoping, Sweden
Email: jorek@ikp.liu.se

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Words From the Chief Scientist
Toward a General Theory and Taxonomy of Behavior

Michael Fineberg

This theory of human behavior under stress is discussed here in the hope that you will put it to the test. If the theory has any relevance to what you're doing, try it as an explanatory framework. I hope you are challenged by what follows.

The *American Heritage Dictionary of the English Language*, 1992 edition, defines taxonomy as "the science, laws, or principles of classification; systematics." Within the behavioral sciences, the definition has been equally vague. DeGreene (1970) defined taxonomy as a "verbal description using an object-verb format." In his view, they are essentially lists of verbs in hierarchical order that reduce behavior from higher level "observable and measurable behaviors" down to a fine level of "meaningless abstraction from the real world." Other authors (e.g., Levine & Teichner, 1971; Meister, 1985) have included another idea, i.e., that it is crucial to understand and make explicit the model or theory of behavior underlying the structure of a taxonomy. A taxonomy then, is not merely a list of labels with semantic definitions; it also must have syntactic structure.

Developing a general theory of behavior (GTB) and taxonomy for both individuals and groups for multiple analytical purposes is a common thread that runs through much of the taxonomy research (Fineberg, 1995). Such a taxonomy would allow behavioral scientists, computer scientists, engineers, trainers, and operational users to exchange data within a common framework and eliminate the need to develop a new taxonomy for each new situation. Meister (1985) states that such a behavioral theory and taxonomy are required to analyze behavior to its constituent elements, to compare or relate two sets of tasks by their common underlying characteristics and behaviors, and to serve as the common basis for managing behavioral data.

The Theory

In response to this need, I have synthesized a general theory of behavior from others' efforts to understand the relationships among the factors that underlie human behavior under stress. It is my hope that the GTB shown in Figure 1 will provide a context for understanding the interaction of those behaviors introduced in the taxonomy discussed later. In deference to Meister, GTB links the behaviors to their antecedents "through individual and team preparation for combat" and to their consequences in terms of combat performance measures.

The GTB is based on the work of several authors in the fields of human performance measurement and stress research beginning with Cannon (1932) and Selye (1952, 1955, 1956) through the more recent efforts of Alluisi (1982), Lazarus and Folkman (1984), Gal (1985), Fineberg et al. (1996), Conroy et al. (1992), and Deitchman and Fineberg (1994, 1995). The GTB bridges the gap between battlefield stresses such as suppressive fire; the sensory, psychomotor, cognitive, social, and emotional responses to such trauma (stress symptoms); and the performance decrements as in individual or team tasks.

The GTB suggests that the antecedent conditions of generic battle stress (D1) and the specific combat tasks associated with particular scenarios (D2) interact to create a demand on the individual soldier or team. Battle stress is influenced by variables such as combat intensity, weather, terrain, threat characteristics, force ratio,

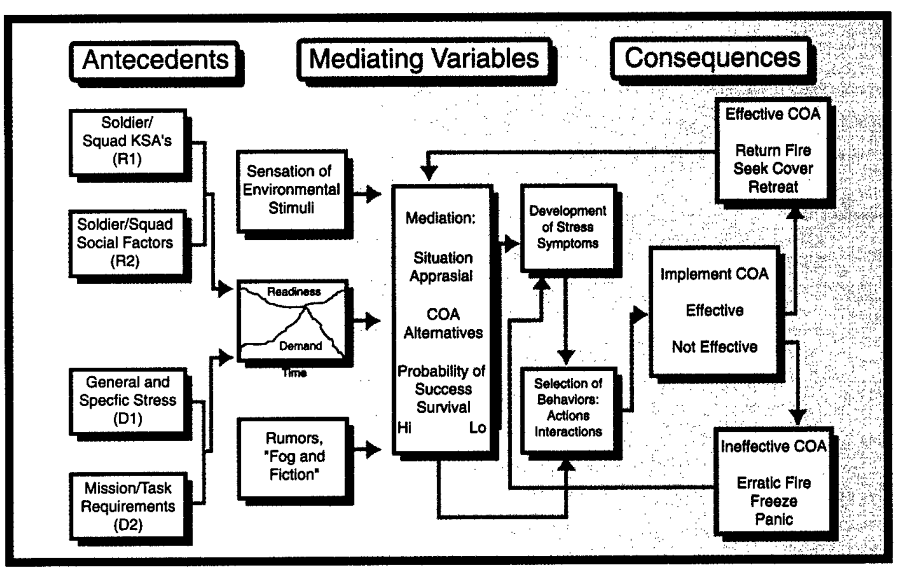

Figure 1. A general theory of combatant behavior under stress.

environmental toxins, wounds, and disease. The combat tasks to be accomplished influence demand through attributes such as number and duration of outputs required, difficulty of goal attainment, precision, response rate, and procedural complexity (Fleishman & Quaintance, 1984).

This resulting demand is met by another antecedent condition, the *level of readiness to perform.* Readiness is a complex function of an individual's knowledge, skills, abilities (KSA) and experience (R1) and interpersonal factors resident in his team and unit (R2). Abilities and traits include comprehension, expression, fluency of ideas, originality, memory, problem sensitivity, math reasoning, induction and deduction, and flexibility (Fleishman & Quaintance, 1984). Interpersonal factors include leadership, cohesion (horizontal bonding among personnel), commitment (vertical bonding to some ideal), role in the organization, and personal well-being (Blades, 1986).

Demand and readiness are compared (either consciously or unconsciously) and the result yields an initial estimate of one's own ability to meet the perceived demand. For example, if readiness greatly exceeds demand, no negative effects on performance are perceived. As time passes, readiness may degrade, while demand may remain steady or grow. In any case, when demand begins to approach the remaining readiness level, individuals use reserve capacity to meet the demand as predicted by the General Adaptation Syndrome (Selye, 1956). At this stage, additional demands may cause the system to break down. The size of the readiness deficit and the individual's predisposition determine the character, prevalence, and magnitude of the performance decrement. This perception or estimate of one's ability to meet further demands, plus knowledge of the tactical situation on the ground and prevailing rumors and confusion, feed into the mediation process in which appraisal of the situation and formulation of a course of action occur.

During mediation, the soldier forms a subjective appraisal of his chances of survival and success. This is based not on the situation per se, but on what the combatant tells himself about that situation. One is tempted to conclude that a low probability of perceived success will inhibit behavior, but risk-seeking behavior cannot be discounted. Perceived probability of survival and success, combined with adherence to appropriate tactics and doctrine, influence the selection and implementation of effective behaviors. If the perceived probability of survival and success is high, the soldier or team will use its training to select and employ the most appropri-

Continued on page 8

ate behaviors in a course of action designed to resolve the situation. If this probability is perceived as low, selection of behaviors will be "detoured" through a set of stress symptoms that tend to reduce the appropriateness and effectiveness of the behaviors and interactions selected relative to the task at hand.

The effect of the decrements in behavior modifies the initial capability of the individual or team by some percentage, leaving a residual capacity to perform. This residual capacity, as influenced by stress responses, translates to performances that are adaptive (advance or retreat) so long as they are not overly influenced by the stresses that drive them. Performance becomes maladaptive (panic and decisional paralysis) when the stress level exceeds some internal, idiosyncratic threshold.

The Taxonomy

The GTB taxonomy described in detail in Fineberg (1995) and Fineberg et al. (1996), is based on the behavior description and requirements approach described by Fleishman and Quaintance (1984) and on an information-processing paradigm. The taxonomy contains four major taxons or classes of behaviors: Sensation, Mediation, Reaction, and Interaction. These major classes are analyzed further into 11 lower-level categories that are populated by over 180 action verbs. These action verbs are seen as building blocks of human behavior.

Taxon A, Sensation, contains the first two subclasses, automatic and volitional behaviors that serve to collect, filter, condition, and retain data from the outside world for short periods. These data are passed on to Taxon B, Mediation, whose behaviors are subdivided into three categories: preparing information for assessment, solving problems, and making decisions. Taxon B also includes the capability to revise decisions based on knowledge of results. Taxon C, Reaction, implements the selected course of action by way of three additional categories of behavior: physical, psychomotor, and conceptual responses. It keeps track of the results of these responses relative to task accomplishment. The behaviors in Taxon D, Interaction, communicate, coordinate, and advocate the selected course of action to superiors and implement this course of action by accessing three subcategories of behavior designated: controlling, organizing, and leading.

If you have new components to add or relationships to suggest, let me know and I'll attempt to integrate them into the framework. Any theory is only as good as its ability to generate creative thinking. Please share your thoughts with me by email, fineberg_michael@bah.com or telephone, 902-703-517. ●

Michael Fineberg, Ph.D., is the Chief Scientist for the CSERIAC Program Office.

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GATEWAY

Air Force Research Laboratory Human Effectiveness Directorate Colloquium Series

The Power and Limits of Problem Solving: Status and Future Prospects of AI Applications

Herbert Simon

Editor's note: In June 1995 we observed the 50th Anniversary of the Armstrong Laboratory Fitts Human Engineering Division (now the Air Force Research Laboratory Crew System Interface Division). Dr. Herbert Simon, University Professor of Computer Science and Psychology, Carnegie Mellon University, provided the keynote address. A synopsis of his address was prepared by Dr. Michael McNeese, Air Force Research Laboratory Crew System Interface Division, Wright-Patterson Air Force Base, OH. JAL

Situations beyond routine activities create problems, and hence problem solving, especially for situations that are changing and that involve complex systems. Problems are multidimensional, can present varying degrees of difficulty, and can lead to different outcomes along different solution paths. The progress of science means solving hard problems, as in the conduct of everyday life.

Process of Solving Problems

Problem solving begins with the recognition that there is a problem, and proceeds toward finding a way to represent it–to define a "problem space" that describes the objects with which it is concerned, their properties and mutual relations, and the means available for changing the situation, moving from one point in the problem space to another, advancing toward the goal. The problems we encounter professionally usually involve not just a single problem solver but many, with all that this implies for the interweaving of their technical, organizational, and social facets, all of which have to be dealt with (McNeese, 1992).

A large class of problems, usually called design problems, do not come with alternative solutions already formed; instead, the core of the problem is to generate these alternatives. Design problems go well beyond engineering and architecture. Creating a business firm's marketing strategy is a design problem; so is forming a strategy for a military campaign.

Whatever the form of a problem and the sources of its complexities, expert problem solving calls on knowledge and search. If the knowledge is to be usable, it has to be organized in memory in a particular way, closely resembling a richly indexed encyclopedia. Research has shown, in every domain where expertise has been studied, that the expert is able, by training and experience, to recognize a large number (perhaps of the order of 100,000) familiar patterns that commonly appear in problem situations (for examples, the symptoms the physician recognizes or identifies by tests, the patterns of pieces on a chess board, indications of enemy troop movements). Associated with these patterns is knowledge that is relevant to solving the problem signalled by the pattern. What is usually called "intuition" or "insight" is precisely this pattern recognition and information retrieval process, fundamental to expert

problem solving but not mysterious.

Combined with this pattern-recognition skill, the expert must have general problem-solving skills (like reasoning from goals to means for accomplishing them) and search tools that are specialized to the task domain (for example, knowledge of the mathematics needed to analyze aerodynamics problems, and to build computational models for them).

Computer Modeling of Problem Solving

For the past 40 years or so, artificial intelligence programs for computers have been advancing our understanding of problem solving–the processes used by human experts in solving problems in their professional domains. The theory of expertise I have just sketched comes largely out of such research and the accompanying experimentation.

Computers have been providing us with a powerful tool to enhance our problem-solving powers, both by assisting human problem solvers, and sometimes by replacing them. Both developments, computer simulation of human thinking, and the deployment of artificially intelligent expert systems, are proceeding today at an accelerating pace. The remainder of my comments will deal with both these developments, and, because I know them best, I will draw my main examples from research at Carnegie Mellon University (CMU).

I have already sketched the shape of the theory of problem solving that has emerged from the research. The theory itself has been formalized in the form of computer programs, for example, the General Problem Solver (GPS; Newell & Simon, 1972), and Soar (Newell, 1990). These theories have been tested by obtaining thinking-aloud protocols from human problem solvers and comparing them with the computer traces on the same problems. In this way, we can determine the capacities of human short-term and long-term memory, the rates at which people can process information, preferred forms of representing information that make it easy to process, and information requirements for various tasks and goals.

The research has also encompassed learning processes, for expertise has to be acquired. Considerable success has been achieved in building curricula for teaching high school mathematics, for example, by means of carefully designed sequences of worked-out examples, which largely replace lectures and textbooks, and which in several cases have been embodied in computer tutors (Anderson et al., 1995).

An important and exciting line of research has explored the role of mental imagery–the "mind's eye"–in reasoning about complex problems with the aid of diagrams, and the interaction between diagrammatic and verbal reasoning. Many important properties of mental imagery can be detected in a rather simple way. If the reader of these lines will form an image of a cat, for example, then we can determine whether the image is a frontal or a side view, what features of the cat are present in the image, whether the view changes when a question is asked about the length of the cat's tail, or whether the image zooms when it is asked whether the cat's eye has lashes or eyebrows.

This trivial example provides a great deal of information about imagery: that words can prompt the formation of a mental image, and change the image and the information displayed in it. At the same time, the image is scanned to reveal new information. The visual processes draw information both from the perceived world (e.g., What threat is launching on my radar screen?) and from visual information already stored in memory (What does that kind of cloud imply for the weather?).

In our research we have experimented on the uses of diagrams to aid reasoning. For example, economics teachers routinely use supply-demand diagrams to explain the effects on prices of changes in costs. What does the student have to know and to "see" in the diagram, to follow the explanation, or to arrive at it in the first place? It is easy to learn by rote that the intersection between two lines represents the equilibrium of supply and demand quantities and prices; it is much harder to use the diagram to explain what would happen if the price lay above the intersection.

Similarly, a simple diagram can be used to capture Einstein's argument on special relativity about the times involved in the reflection of a light ray speeding along a moving rod. However, it required careful research to show that subjects could come to understand what was going on more effectively if shown the before-and-after static situations, than if presented with a display on a computer console, complete with clocks, of the changing situation as it unfolded. (This particular experiment contains a warning, by the way, for those who might believe that understanding always increases with the realism of the visual image–that a dynamic display is always superior to a static one, and "virtual reality" to less realistic images.) Sometimes less is more.

In the research on imagery, cognitive simulation also plays a central role. A computer model of the mind's eye, called CaMeRa (Tabachneck, Leonardo, & Simon, 1997), provides a set of mechanisms, a theory, of the processes of human thinking that solve the supply-and-demand problems I described, and reach an understanding of the special relativity argument about the light ray.

I hope that these small samples will give a glimpse of the ways in which computer simulation of human problem solving is deepening our understanding of human thought processes in complex situations. I would like to conclude with an even briefer sample of the prospects for automated expert systems and systems for human-computer collaboration. Already many such systems are familiar, albeit in rather primitive form.

There is, for example, CAD-CAM, which is today little more than a clerical aide to the human draftsman and scheduler, but which will gradually take a larger and larger part in design and scheduling decisions.

With the accelerated (and rather chaotic) growth of computer communications and networking, we see enor-

mous interest in search engines to extract information we want from this burgeoning mass of data. To be useful, it is not enough for these engines to extract; they must select and filter, and the filtering must not be random but intelligent. Data mining and data routing will be one of the most active and most important areas of AI investigation over the next decade.

Then there is the matter of "groupware": computer software to manage communications and files that support group collaboration in organizations. Again, we see primitive beginnings of such group aids, but also a mountain of problems relating to file "ownership," rights to modify, certification of revised versions, confidentiality–all the problems that have been faced, and more or less solved, in human organizations, but that require drastically revised solutions to fit (and take advantage of) a radically new technology. As an example of military interest, I mention designing and implementing the electronic logistic systems for Desert Storm, in which some of my CMU colleagues played an important role.

Conclusions

Because complex systems use and are dependent upon human problem solving, and increasingly on computer problem solving, for fitness, survival and success, human factors specialists, cognitive engineers, and cognitive scientists need to understand how electronic interfaces and intelligent agents can support and enhance problem solving. Through continuing research in the two branches of artificial intelligence, cognitive simulation and expert systems, we can gain the knowledge that designers need for building effective intelligent systems and human interfaces with them. The study of cognition, human and machine, is increasingly revealing to us the nature of intelligence and the workings of the mind.

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Air Force Research Laboratory Human Effectiveness Directorate Colloquium Series

A Conversation With Herbert Simon

Reuben L. Hann

Editor's note: Following is an edited transcript of a conversation with Dr. Herbert Simon, University Professor of Computer Science and Psychology, Carnegie Mellon University (see Fig. 1). He was a guest during the 50th Anniversary of the Armstrong Laboratory Fitts Human Engineering Division (now the Air Force Research Laboratory Crew Interface Division). The interviewer was Dr. Reuben "Lew" Hann, former CSERIAC COTR. Dr. Hann, now retired, kindly prepared this transcription. JAL

Figure 1. Dr. Herbert Simon, Carnegie Mellon University.

CSERIAC: Your autobiography describes you as a "... political scientist, organization theorist, economist, management scientist, computer scientist, psychologist, and philosopher of science."

Dr. Simon: I believe you will find that the next sentence after that says: "...but I have really been doing only one thing." As an undergraduate I got involved in a little research project examining how the city public works department and the city education department made budget decisions about the city playgrounds. I became intrigued with the whole process of human decision making. That's really what I have been doing ever since. Economics was involved in the decision making; we had to understand the psychology of it; then computers came along, which were the obvious tool for constructing a psychological theory of the mind. So, for me, these areas really were all related.

CSERIAC: You wrote that "...the logic of discovery is quite different from the logic of verification." Could you explain what that meant?

Dr. Simon: Certainly. Philosophers of science for a long time have been concerned with how you verify that something is true—statistical testing theory and such. Popper wrote a book—interestingly enough called "The Logic of Discovery"—but the book denied there was a logic of discovery and really talked about verification. If, by "logic," you mean ways of doing things more reasonably than not, then there are reasonable ways of going about discovery—not of *guaranteeing* discovery, but reasonable ways of going about it. That's what I call the logic of discovery. In our research on scientific discovery we have tried to exhibit some of that logic by building systems that can make discoveries. One way we exercise these systems is to provide the same initial knowledge that existed at the time of an important historical human discovery, and then see where it ends up. So, we gave a computer program called *BACON* the data that Keppler had about the distances of the planets from the sun and the periods of revolution, and asked, "What do you make of this?" After a few seconds it came up with Keppler's Third Law. That's the game we have been playing: How can you account for genuine major scientific discoveries?

There is another route one of my students, Raul Valdes-Perez, is pursuing. Namely, can you build a system to make *new* discoveries? He has a program called *MECHEM* which is given information about some of the inputs to a chemical reaction, some of the outputs (they need not be complete), as well as some of the intermediate products. *MECHEM* will then infer a reaction chain. That system is good enough that he has published four or five pieces in chemical journals—not in AI journals—which is significant. He thinks he has found several plausible new reaction paths for important known reactions; these reactions have not been fully understood thus far. That is the test: Can you come up with new discoveries, which are significant enough to be published in professional journals from that discipline?

CSERIAC: You received the Nobel Prize for Economic Science in 1978. One of the most controversial concepts from your work is "bounded rationality." Could you explain what this means?

Dr. Simon: If you look at standard economic theory, they start with the heroic assumption that a businessman or consumer—or anyone making a buy-or-sell decision—is sitting there with all the alternatives in front of them. Then they have something called a "utility function"—a way of evaluating things; they find the maximum value and that is the decision. Life should be so simple.

What we found is that people make their search only until they find something that's useful or expedient, and looks good in terms of their personal experience. Then they stop the search and go with their decision.

CSERIAC: In 1949 you went to work at Carnegie-Mellon in the business school. There you became involved with the Rand Corporation and with Allen Newell, and in 1955 you went "...from being a political scientist/economist to a cognitive scientist/psychologist." What caused the switch?

Dr. Simon: The group was working on the simulation of an early-warning system, with simulated inputs from flight patterns. The only way they could figure to do that was to compute where the flights were at each second or so, then print a map of the radar spots on paper. They used that as the simulated radar scope. Remember, until this time the computer was considered nothing more than a high-speed calculator—that it could only deal with numbers. Well, I looked at their simulated radar scope printouts and realized that we were dealing here with *patterns*, not numbers. A computer could obviously do anything you can do with patterns. That was my insight. Incidentally people were using computers already at that time to play chess, but they still thought of it as translating chess to numbers, not patterns.

CSERIAC: You taught yourself to program an IBM 701 and developed what could be called the predecessor to LISP. How did this happen?

Dr. Simon: We knew, for these kinds of problems, there was no way of assigning memory arrays to various events. Furthermore, there wasn't enough memory to leave anything permanently assigned. So we needed to have a flexible way in which anything could become anything, so to speak. List processing was the way to do this. It really took the systems programming community—even after LISP was around and running well—almost 10 years until they began to bring list processing into the construction of operating systems.

CSERIAC: You and your colleagues were the fathers of Artificial Intelligence.

Dr. Simon: We have been accused of that. At the time we called it "complex information processing."

CSERIAC: We have not heard much lately about AI—at least not in the press. Do you think it was over-hyped?

Dr. Simon: Actually, I don't think it has been greater than the hype in any other new field. What made AI different was that the very idea of it arouses a real fear and hostility in some human breasts. So you are getting very strong emotional reactions. But that's okay. We'll live with that.

CSERIAC: You talked today about display fidelity, saying that virtual reality has to be approached carefully. Why is that?

Dr. Simon: Well, just making the picture more "real" doesn't necessarily make you understand or learn more. So, it seems to me, in developing virtual reality ideas as a part of how we are going to operate computers, we need to find out what it *is* about virtual reality that either educates or confuses. Maybe the word "reality" is wrong. I think the word carries for many people the implication that if you can create a reality that is so real people feel they are in it, that this is automatically beneficial—that you automatically learn from it. That may not be necessarily true.

In our old System Research Lab study the simulation was so "real" that the airmen who were participating in the study actually wept when the "Russians" got through the defenses and "bombed Seattle." How could they sit in that room for six hours or more a day and not begin to feel that they were really running an early warning station? Well, did that make it more educational or less educational? It's not clear. That's really my warning: more complex isn't necessarily better; you had better understand what the process is.

CSERIAC: You have said you would "...like to understand the cognitive roots and mechanisms of mathematical competence and incompetence. There is no question I would more like to answer before my research career ends." Why do you feel so strongly about this?

Dr. Simon: Because I think it has very large social consequences. We live in a very high-tech world and large numbers of people feel shut out from that world. It makes them hostile to it. They very closely connect their inability to penetrate that world to its mathematical character. And, as long as they carry around that mathematical fear and ignorance, I don't see how you can get them into a state of mind where they feel they are a part of that world. I think that's extremely dangerous in the kind of world we live in. I find it interesting that in our society it is socially acceptable to say "I always was stupid in math." No one is embarrassed to say that. But it is *not* acceptable to say "I never could speak English well."

CSERIAC: I will close with a question about the future. What do you think the "hot spots" will be in cognitive psychology/cognitive science as we enter the next century?

Dr. Simon: Well, I suppose my crystal ball is about as good as anyone else's, but one of the areas I find exciting now is visual imagery. For instance, finding out how we do reasoning that's clearly not verbal or logical in the syllogistic or propositional sense. What are those kinds of reasoning? What does it take to make them function? And then the related question: What are all these different ways of representing knowledge in the brain? There may be ways we don't even know of yet. After all, the calculus has not been around forever; it got invented at some point. It is a powerful way of representing large numbers of systems of a certain kind. So, where do representations come from and how does any individual acquire a representation and the ability to reason in it and feel that reasoning in it constitutes understanding of the phenomenon? Those seem to me very critical areas. Of course, associated with each one are learning questions: How do we learn to do these things? ●

Naval Air Warfare Center Aircraft Division Crewstation Technology Laboratory

Lisa B. Achille

The Crewstation Technology Laboratory (CTL) is located in the Human Engineering Applications Branch in the Crew Systems Department at the Naval Air Warfare Center Aircraft Division, Patuxent River, Maryland. The department staff and CTL provide human engineering support to the Navy for acquisition of aviation materiel in all phases of the life cycle. The primary role of CTL is to enable integration of advanced technologies into crewstation designs for Naval and Marine Corps aircraft through the development and execution of behavioral test methods and analyses. Man-machine integration technology of all types is involved including lab, ground, and flight testing of crewstation equipment and systems. The unique facilities of CTL provide advanced flight and mission task simulation, computerized rapid prototyping, image processing and graphic workstation test support applications, video-based test documentation and behavioral data analysis. All of these are tailored to the high tempo of aviation research, development, testing, and evaluation support.

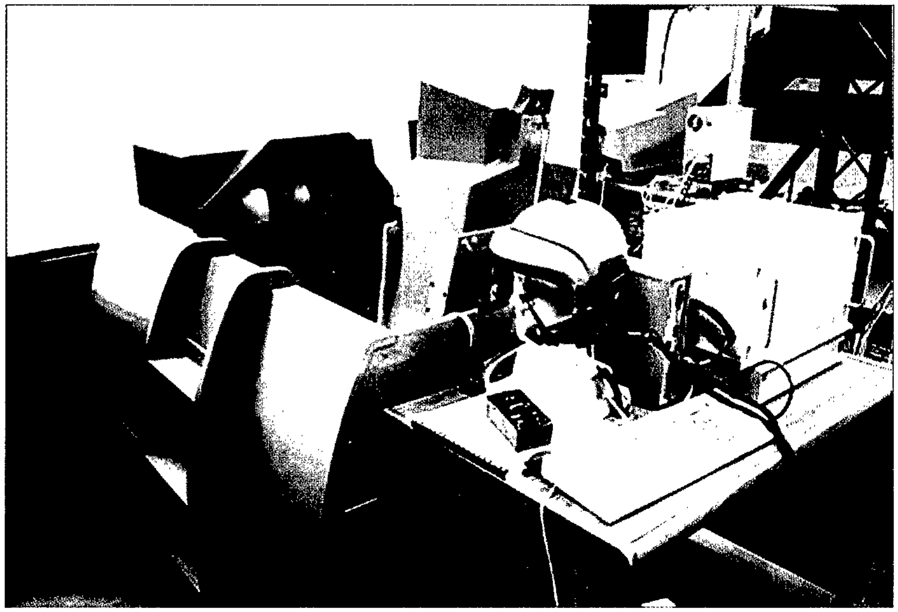

Figure 1. Resources of the CTL include a variety of cockpits and an extensive collection of helmet-mounted displays.

Capabilities

The Laboratory has expertise and test and evaluation capabilities in several areas related to the incorporation of advanced technology into crewstation design. Historically, one focus of our work has included establishing the design requirements for and testing of helmet-mounted displays (HMD) and associated head trackers. CTL holds high- resolution, full-color HMD's and various trackers for both flight testing and simulation (see Fig. 1). Extensive methods development has included system evaluations using eye-tracking measures; performance, workload, and task analysis; adaptive automation, video data analysis, and display symbology. Advanced facilities and procedures in all these areas are available at CTL.

The Laboratory is well equipped to simulate a variety of display devices. Facilities include a collection of HMD's, networked cockpit simulators including Distributed Interactive Simulation (DIS) capabilities, large screen displays, and a virtual workbench capable of presenting three-dimensional, stereoscopic displays. CTL also has extensive computing power and the software and development capability to rapidly prototype specialized or research-oriented displays, crew stations, and detailed terrain models for simulation.

Human Engineering Tools and Techniques

In addition to executing tests and evaluations, CTL's function is to design, develop, and refine its own procedures, methods, and equipment to facilitate its mission. In response to the need for quantitative tools to gauge human performance capabilities, CTL has developed several specialized yet flexible tools and techniques. Four are described below.

Critical Tracking Task

The Critical Tracking Task permits evaluation of many aspects of pilot workload. The Critical Tracking Task software provides a variety of control tracking tasks that can be scaled to dynamically increase subject workload with full performance measurement and performance feedback control. Tracking control order can be varied from zero-order (position) through

third-order ("jerk" or changing acceleration) control. The task has numerous applications in system and workload testing.

Frequency-Weighted Task Complexity Index (FWTCI)
The FWTCI is CTL's rapid processing and scoring technique developed for time-varying data (e.g., manual tracking task data). When applied to manual tracking tasks, the process converts stick movement data by fast Fourier transform techniques to a perspective spectral array (PSA) for visual inspection of time and frequency domain information on a three-dimensional plot. From this, a new function, the FWTCI, is computed as a summary measure of task difficulty.

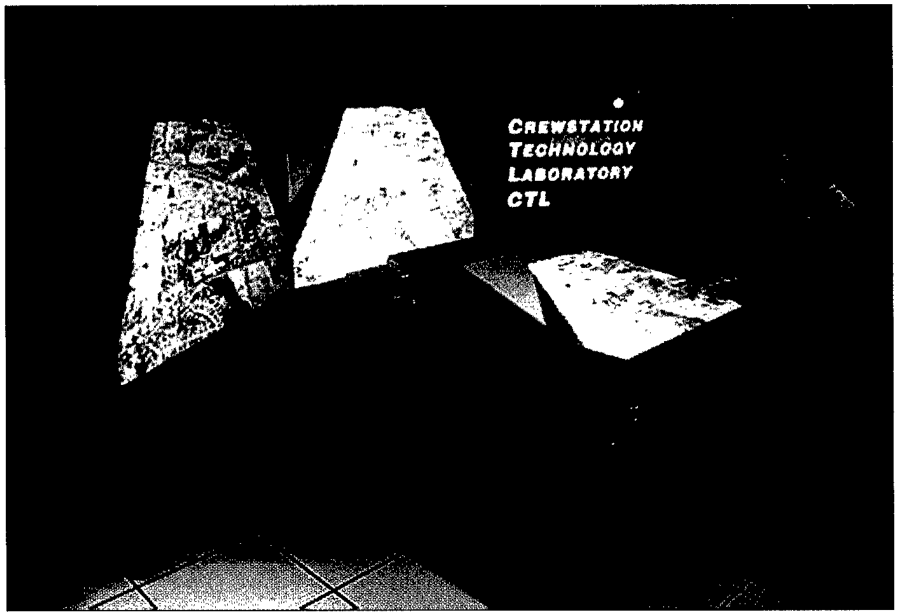

Figure 2. Dr. Richard Dunn demonstrates the presentation capabilities of VAT.

Prime capabilities developed in video-based test applications include:

Video Recorder Multiplexer Demultiplexer System (VRMDS)
This is a custom-built system used to document crew performance for task evaluation and analysis. This system was developed for in-flight video recording to document crew performance for task analysis verification. It is capable of recording up to eight different time-sequenced video streams as well as digital data-streams on one standard VHS tape. The VRMDS can take input from digital cameras which provide high-quality images. Individual video streams can then be demultiplexed for post-test analysis.

Video Information Extraction Workstation (VIEWS)
This is a workstation for task analysis and activity sampling based on video tape input and hosted on a graphic workstation computer. The VIEWS enables human factors engineers to more effectively and efficiently analyze task data from videotapes or other data streams recorded from aircraft, simulation, or ground tests. Data sources may include head trackers, physiological measurement equipment, or any synchronous or asynchronous source that can be time-referenced to test events. The system digitizes video and test data, allowing direct access and manipulation for easy scoring, annotation, and analysis in accordance with a user-defined schema.

Current Efforts

A current major focus at CTL is the Visualization Architecture Technology (VAT) project (see Fig. 2). This effort is to develop advanced visualization software, and both standard and stereoscopic display capability. The goal of VAT is to develop and demonstrate the power of visualization technology to provide a clear depiction of tactically relevant information for complex operations. The approach involves combining advanced, three-dimensional, stereoscopic display systems with high-resolution, geo-referenced imagery and communications network connectivity in a real-time command and control environment. The development of this capability will permit the evaluation of information handling and processing, and decision support technologies for future systems designed to manage the increasingly complex array of information available to warfighters and commanders. The ultimate goals include the enhancement of command situation awareness and tempo of operations, as well as improved mission planning and control.

Staff

The CTL is permanently staffed by a multidisciplinary team including engineering psychologists, mathematicians, optical and electrical engineers, computer scientists, and engineering technicians. For special projects, we employ visiting scientists and collaborate with Navy scientists and researchers from other facilities. ●

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